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Three-dimensional evaluation of postoperative stability: a comparative study between surgery-first and surgery-late protocols

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Abstract. The main objective of this study was to compare the stability of the surgery-first and surgery-late approaches according to the standardized centre protocols, by three-dimensional evaluation after 1 year of follow-up. A retrospective study was designed that included a test group (surgery-first protocol) and a control group (surgery-late protocol), with a follow-up period of at least 1 year (average 14 months; range 12–24 months). Stability was evaluated using linear and angular measurements by superimposing cone beam computed tomography images obtained at specific points in time: preoperatively, 1 month after surgery, and at the end of the orthodontic treatment. A total of 56 patients with a mean age of 32.2 ± 11.1 years were included in the study. After surgery there were significant changes in all of the measurements in at least one dimension in both groups (except for the transverse maxillary dimension), which remained stable at the end of the treatment, with no statistically significant differences between the two groups. At the 1-year follow-up, both groups presented a SNA angle relapse; this relapse was more significant in the surgery-late group ($P = 0.031$) and was present only in Class III patients ($P = 0.013$). In conclusion, an equivalent three-dimensional stability between surgery-first and surgery-late protocols was demonstrated after 1 year of follow-up when eligibility criteria were strictly adhered to.

Keywords: Dental occlusion; Orthodontics; Orthognathic surgery; Three-dimensional imaging; Virtual reality.

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In recent years, there has been a shift in how patients with malocclusion and dentofacial deformities are treated. The traditional ‘orthodontics before surgery’ approach, or so-called surgery-late (SL) protocol,[1] where surgery is performed after orthodontic treatment, was the norm until recently. In pursuit of improving patient satisfaction, there has

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been a re-popularization of a previously used surgical approach[2] consisting of surgery before orthodontic treatment, which was proposed by Nagasaka et al.[3] in 2009 for skeletal Class III patients. The objective of this latter approach was to reduce the disadvantages associated with the conventional sequence of the SL protocol by decreasing the total treatment time and offering the patient an immediate aesthetic improvement. The surgery-first (SF) protocol for orthognathic surgery involves the correction of the jaws and soft tissue before the teeth and the occlusion, and does not require a pre-surgical orthodontic treatment of decompensation and arch leveling.[4] By starting the treatment with surgery, an immediate improvement in the skeletal discrepancy, upper airway volume, and facial aesthetics can be achieved,[5] and the period of 'clinical worsening' seen during orthodontic decompensation is avoided. Surgery is followed by post-surgical orthodontics to complete the treatment to obtain a correct dental occlusion. Patients treated following the SF protocol have been shown to be more satisfied, cooperate better, and have a higher quality of life.[6–8]

Thanks to three-dimensional (3D) imaging and virtual surgical simulation, the prediction of bone and dental movements with surgical and orthodontic treatment, respectively, is now more reliable. In addition, improvements in rigid fixation hardware and the development of specific techniques tailored to the protocol have enabled correct stability after surgery without requiring a previous orthodontic treatment.[9] In this case, a virtual orthodontic setup must be done to predict the final dental occlusion, especially the inclination of the incisors, in order to establish a surgical treatment objective. This dental prediction, although challenging, must be accurate.[10]

With the SF approach, the overall duration of treatment is reduced, due to an elimination of approximately 12–24 months of pre-surgical orthodontic treatment[5,11,12] and an increase in the efficiency of postoperative orthodontic treatment. Orthodontic treatment after a surgical procedure to the jaw is accelerated two-fold in comparison to conventional orthodontic treatment due to the so-called systemic and regional acceleratory phenomenon (SAP[13] and RAP,[14] respectively), an increased metabolic turnover secondary to osteotomies that has been shown to accelerate the tooth movement, with a peak activity during the first 2 months after surgery.[9] The SAP/RAP, together with a surgically corrected maxillomandibular relationship and an elimination of possible soft tissue/muscular interferences, has been shown to significantly reduce the overall orthodontic time and difficulty.[15] The use of temporary skeletal anchorage devices and microscrews has also been shown to shorten the duration of post-surgical orthodontic treatment.[11]

Skeletal stability can be defined as a lack of relapse or an absence of an unfavourable sagittal/transverse/vertical movement of the maxilla and/or mandible after surgery, measured using 3D cephalometric reference points. Various authors have reported that the SF approach is as stable and predictable after surgery as the conventional SL approach.[5,9,12,16,17] However, the long-term stability is still unclear.[18] The main objective of this study was to compare the stability of the SF and SL approaches, performed using the standardized protocols of the study centre, after 1 year of follow-up.

2. Materials and methods

2.1. Sample selection

A retrospective analysis was conducted at the Maxillofacial Institute, Teknon Medical Center (Barcelona, Spain) to compare the stability of the SF and SL orthognathic surgery protocols.

The study was designed to include two groups defined according to the surgical timing protocol followed (test group, SF; control group, SL), with a follow-up period of at least 1 year. Data were collected from the medical records of the patients operated on between January 2016 and December 2019.

Patients over the age of 18 years (with a complete maxillofacial development) with an underlying dentofacial deformity in need of bimaxillary surgical and orthodontic correction were included. Patients with an isolated bilateral sagittal split or Le Fort I osteotomy were excluded, as well as those presenting a craniofacial syndrome and those who missed follow-up visits. Specifically, the current indications for including or excluding patients from a SF approach[19,20] are listed in Table 1.

The study was approved by the Ethics Committee of the Teknon Medical Center (Barcelona, Spain) (Ref. SF-SC) and was conducted in accordance with the ethical standards laid down in the Declaration of Helsinki (1964 and later amendments).

2.2. Diagnosis protocol and virtual planning work-up

Each patient underwent the standard workflow of the Department for Orthognathic Surgery planning and surgical splint fabrication, as described elsewhere.[21] The protocol is based on a

Table 1. Inclusion and exclusion criteria for the surgery-first approach.

	Inclusion criteria	Exclusion criteria
Patient	Desire for an immediate aesthetic improvement Treatment for sleep-related breathing disorder	Does not understand the protocol Has unrealistic expectations
Treating team	Agrees on a reduced treatment time protocol	Inexperienced in orthognathic surgery
Occlusal	Minimal crowding of the anterior teeth, not requiring tooth extraction	Severe crowding requiring extractions Class II second division malocclusion with an overbite Very deep curve of Spee
Dentoalveolar		Asymmetric dentoalveolar compensations
Skeletal		Maxillary transverse discrepancy of more than 6 mm Severe asymmetries with 3D dental compensations
Others		If applying SF protocol implies modifying the surgical plan Periodontal disease (until treated) Unstable temporomandibular joint disorder (until stabilized)

3D, three-dimensional; SF, surgery-first.

single cone beam computed tomography (CBCT) scan of the head of the patient (i-CAT, Imaging Sciences International, Hatfield, PA, USA) and intraoral surface scanning of the dental arches using a Lava Scan ST scanner (3 M ESPE, Ann Arbor, MI, USA). The two datasets are imported and fused using a software program (Dolphin 3D Orthognathic Surgery Planning Software version 11.8; Dolphin Imaging & Management Solutions, Chatsworth, U.S.A.) for pre-surgical 3D planning according to the standardized upper incisor to soft tissue plane protocol of the study centre,[19,22] where a vertical plane passing through the soft tissue nasion (N′) with the patient in natural head position is used as a reference plane for maxillary positioning. Intermediate and final surgical splints are designed accordingly and printed in-house using a stereolithography (SLA) 3D printer (Tiertime UP Box3D; Beijing Tiertime Technology Co., Ltd, Beijing, China).

Specifically for patients treated with the SF protocol, a previous virtual orthodontic setup was performed to establish the final occlusion, especially the final position and axial inclination of the upper and lower incisors. At the same time, the feasibility of a SF approach was verified. This position was then used to plan the surgical movements of the maxilla and/or mandible according to the surgical treatment objective.[23]

2.3. Surgery

Patients were operated on by the same surgeon (FHA) under general anaesthesia with nasotracheal intubation and supplemental local anaesthesia. The mandible was operated first in all cases, and a bilateral sagittal split osteotomy (BSSO) was performed using the Hunsuck–Dal Pont–Obwegeser technique, followed by a Le Fort I osteotomy of the maxilla using the minimally invasive ‘twist technique’.[24]

The following technical specifications were performed in the SF group: bracket bonding was done 1 week before surgery, and a passive NiTi soft arch wire was placed the day before surgery. Intraoperatively, after local anaesthesia infiltration and before surgical incisions, four to eight transmucosal 2.0-mm microscrews were placed for subsequent intermaxillary fixation with intermediate and final splints in place, since hooks cannot be used with soft arch wires. In the case of anterior crowding, interdental corticotomies (osteotomies of the buccal cortex) were performed using a piezoelectric handpiece to further induce the previously stated RAP and SAP, and increase the orthodontic management in this region postoperatively.[14] The intermaxillary fixation microscrews were left in place for the placement of light guiding elastics during the first month after surgery, and for skeletal orthodontic anchorage when needed.

All patients wore a closed-circuit cold mask (17 °C) during their hospital stay and were discharged 24 h after surgery. Identical postoperative recommendations and antibiotic and analgesic medications were prescribed in both groups. Patients in both groups underwent functional training using light guiding elastics and followed a soft diet during the first month. Patients were referred to the orthodontist 2–4 weeks after surgery when enough mouth opening allowed them to start their treatment.

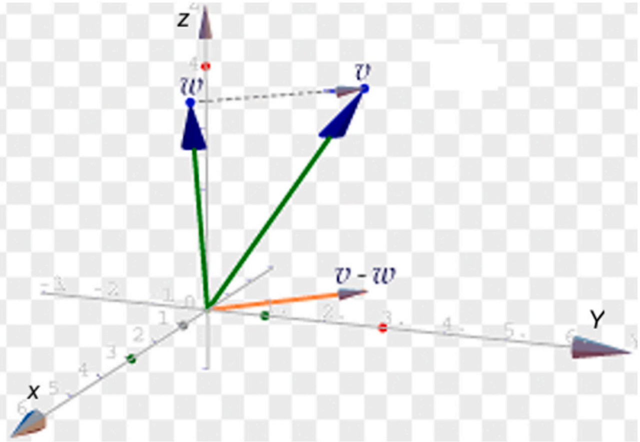

Fig. 1. Graphically, vector ‘*w*’ indicates the position of the posterior nasal spine (PNS) at 1 month of follow-up and vector ‘*v*’ at 1 year of follow-up. The length of the vector difference ‘$v - w$’ is the amount of displacement of PNS.

2.4. Data acquisition and evaluation of study variables

In order to evaluate the stability of each protocol, linear and angular measurements based on several cephalometric reference points were performed by superimposing the CBCT images obtained at three specific points in time: preoperatively (T0), 1 month after surgery (T1), and after the end of the orthodontic treatment, at least 1 year after surgery (T2). Two postoperative time points were chosen in order to evaluate the stability of the rigid fixation system 1 year after surgery. CBCT images were collected in DICOM format (Digital Imaging and Communications in Medicine) and processed with specific software (Dolphin). A 3D volume was created by hard tissue reconstruction for each of the three databases taken (preoperatively and postoperatively at 1 month and 1 year of follow-up). The three CBCT datasets of each patient were superimposed in accordance with the voxel-based superimposition protocol described previously elsewhere.[25] The software tool used for orientation and calibration was based on pitch (X), yaw (Y), and roll (Z) (Fig. 1). The orientation of both the base volume (original DICOM) and second volume (duplicate DICOM) was performed to achieve the same original positions of the CBCTs. Then, superimposition of the preoperative CBCT with those obtained at T1 and T2 was performed using the cranial base, as this structure does not change during surgery. 3D voxel-based superimposition was chosen because it enables unbiased analysis based on software precision, avoiding time-consuming measurements and ensuring that all three virtual images (preoperative and postoperative at 1 month and 1 year of follow-up) are in the same position.[25]

The cephalometric landmarks used are listed in Table 2 and shown in Supplementary Material Fig. S1; these were recorded as coordinates in 3D-space (Fig. 2). Specific angles (SNA, SNB, and SNPg) were measured, as well as the transverse dimension of the maxilla (palate–palate) and of the mandible (gonion–gonion). These measurements are summarized in Table 2, and were used to evaluate the stability of each protocol after orthognathic surgery over time (preoperative and postoperative at 1 month and 1 year of follow-up).

All measurements were evaluated by two previously calibrated researchers (STR and IT). In order to ensure truly accurate and reproducible measurements, the examiners tagged all virtual models independently on two separate occasions (2 weeks apart), thus avoiding inter- and intra-observer differences, respectively. Inter- and intraclass correlation analyses (ICCs) were used to calculate examiner differences and reliability.[26]

In addition, the following demographic variables were recorded: patient age, sex, and preoperative dental class deformity (Class I, II, or III).

2.5. Statistical analysis

A descriptive analysis of the study variables was done, calculating the mean, standard deviation (SD), minimum and maximum values, and median for continuous variables. Absolute and relative frequencies (percentages) were reported for qualitative variables.

For each parameter, the measurement at each of the three time points was described, as well as the absolute differences T1 − T0 (immediate postoperative effect), T2 − T1 (1-year postoperative stability), and T2 − T0 (total effect 1 year after surgery). The absolute displacement of the x, y, z parameter in space was calculated using the following formula:

$$\Delta\ VARIABLE\ (T2 - T1) = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

where ($x1$, $y1$, $z1$) and ($x2$, $y2$, $z2$) are the coordinates of the variable at 1 month and at 1 year of follow-up, respectively.

The Kolmogorov–Smirnov test was used to determine the deviation from a normal distribution of the different dimensions. The deviations involved various variables in one or both groups, more apparent in the differences between the two, so the overall approach of the analysis was non-parametric.

The inferential analysis included the following statistical methods based on the longitudinal design of the study and the non-normal distribution of the dependent variable: non-parametric Bruner–Langer models were estimated for longitudinal data to study the changes in each parameter between two measurement times and according to the protocol; and an analysis of variance (ANOVA) type ATS statistic test was used to evaluate the main effects and interaction. For multiple comparisons (changes within each group), the Bonferroni correction was applied. Spearman correlation coefficients were estimated to assess the degree of non-linear association between changes in parameters.

The level of statistical significance was set at 5% ($P = 0.05$). The statistical model applied reached a statistical power of 83.6% to detect a significant difference in parameter changes between the two protocols equivalent to a mean effect size (f = 0.2), for a confidence level of 95%.

3. Results

A total of 56 patients were included in the study: 29 SF cases (test group) and 27 SL cases (control group). There were 27 female patients (48.2%) and 29 male patients (51.8%), with a mean age of 32.2 ± 11.1 years (range 18–61 years). Most patients presented with an initial dental Class II (30.4%) or Class III (64.3%). The demographic data of each group are summarized in Table 3. All included patients completed a follow-up period of at least 1 year (mean 14 months; range 12–24 months). Analysis of group homogeneity regarding age, sex, and initial dental class showed the two groups to exhibit a fairly acceptable degree of homogeneity.

The skeletal changes over time are summarized in Supplementary Material Table S1. In brief, after surgery there were significant changes in all measurements in at least one dimension in both groups (except for the transverse maxillary dimension), which remained stable at the end of the treatment, with no statistically significant differences between the two groups. Specifically, PNS-z and A point-z measurements changed significantly in both groups, but the change was greater in the SL control group ($P = 0.007$ and $P = 0.039$, respectively), and this persisted at the 1-year follow-up ($P = 0.040$ and $P = 0.065$, respectively). Similarly, the SNA angle was significantly increased in both groups (both $P < 0.001$), but with a trend towards a greater increase in the SL control group, although this was not statistically significant ($P = 0.055$). However, at the 1-year follow-up, although both groups presented a SNA angle relapse, this was more significant in the SL control group ($P = 0.031$); hence the global change from baseline to the 1-year follow-up was similar in the two groups ($P = 0.269$). The correlation test demonstrated that those cases with a greater SNA angle opening, later suffered a greater relapse. The correlation

Table 2. Recorded landmarks on CBCT and list of assessed 3D cephalometric landmarks, linear and angular measurements.

CBCT recorded landmarks	Assessed measurements		
	Cephalometric points	3D lines	3D angles
Sella Nasion Posterior nasal spine A point B point Upper incisor Lower incisor Pogonion Hyoid bone Greater palatine foramen (left–right) Gonion (left–right)	Posterior nasal spine A point B point Upper incisor Lower incisor Pogonion Hyoid bone	Maxillary transverse dimension (from left to right greater palatine foramen) Mandible transverse dimension (from left to right gonion)	Sella–nasion–A point (SNA) Sella–nasion–B point (SNB) Sella–nasion–pogonion (SNPg)

3D, three-dimensional; CBCT, cone beam computed tomography.

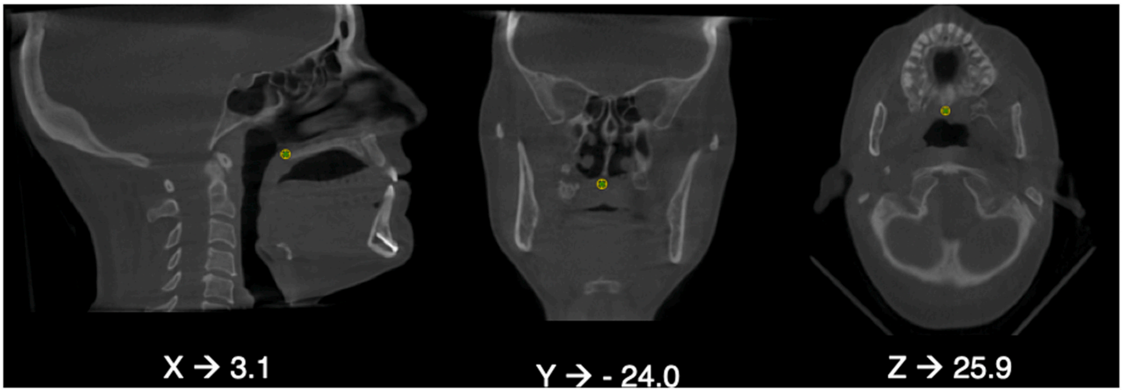

Fig. 2. Example of three-dimensional evaluation of the posterior nasal spine (PNS) landmark positioning on CBCT using Dolphin software: *X*, sagittal view; *Y*, coronal view; *Z*, axial view.

was moderate to strong for the overall sample ($r = -0.63$), as well as for both groups independently (SF $r = -0.59$; SL: $r = -0.68$) (Fig. 3). The remaining measurements also showed significant changes in at least one dimension in both groups, but with no statistically significant difference between the two groups, with the exception of the transverse maxillary dimension, where no significant changes were observed either after surgery or at the 1-year follow-up.

An additional sub-analysis was performed in order to evaluate the effect of the initial dental class on the stability of the protocols: the SF group included 11 Class II and 15 Class III patients, whereas the SL group included six Class II and 21 Class III patients. This analysis with interaction clarified that the higher SNA angle relapse in the SL group was only happening in Class III patients ($P = 0.013$) (Fig. 4). The rest of the parameters did not show relevant differences.

The intra-examiner ICC obtained for measurement displacements was 0.97–0.99 for both of the examiners; the inter-examiner ICC was 0.97.

4. Discussion

With the SF protocol, the patient's quality of life can improve immediately after orthognathic surgery without going through a lengthy preoperative orthodontic period, during which there can be a slight worsening due to the dental decompensation necessary in the classical SL protocol.[6–8] This can be beneficial especially in patients suffering from obstructive sleep apnoea syndrome,[27] and in those with psychological implications. Other benefits of a SF approach have been widely reported in the literature, with a shortening of the overall treatment time being the most noteworthy.[1,5] However, there is controversy regarding the long-term stability of the SF approach compared to the SL protocol,[5,12,18,28] since there is substantial heterogeneity among studies, high reporting bias, and a lack of long-term follow-up.

The current study showed that there is not enough statistical evidence to demonstrate differences in stability between the two groups, so it is concluded that the stability after both protocols is equivalent. However, applying the SF protocol requires careful case selection in order to obtain an acceptable immediate postoperative stable occlusion and predictable final results, since occlusal instability and a high degree of orthodontic tooth movement in postoperative orthodontics may cause relapse after surgery.[18,29,30] Accordingly, the authors recommend following the screening criteria summarized in Table 1, as well as performing an individual evaluation of each patient by the combined orthodontic-surgical team, with confirmation of a stable postoperative occlusion using study models and the complete diagnostic work-up (clinical pictures, CBCT, and intraoral scan), to decide if the SF protocol is the best choice of treatment.

Similarly, selection of the surgical technique and fixation method need to be carefully planned and carried out. For example, the BSSO as a surgical technique has demonstrated better postoperative stability over the intraoral vertical ramus osteotomy due to the reduced bone contact in the latter.[31] Furthermore, surgeries with bimaxillary advancement movements as opposed to setback movements are more

Table 3. Demographic data of the patients in each group.

	Surgery-first ($n = 29$)		Surgery-late ($n = 27$)	
Age (years)				
Mean ± SD	33.8 ± 9.3		31.6 ± 11.6	
Range	22–59		18–61	
Sex, *n* (%)				
Female	15	(51.7%)	12	(44.4%)
Male	14	(48.3%)	15	(55.6%)
Preoperative dental class, *n* (%)				
I	3	(10.3%)	0	(0)
II	11	(37.9%)	6	(22.2%)
III	15	(51.7%)	21	(77.8%)

SD, standard deviation.

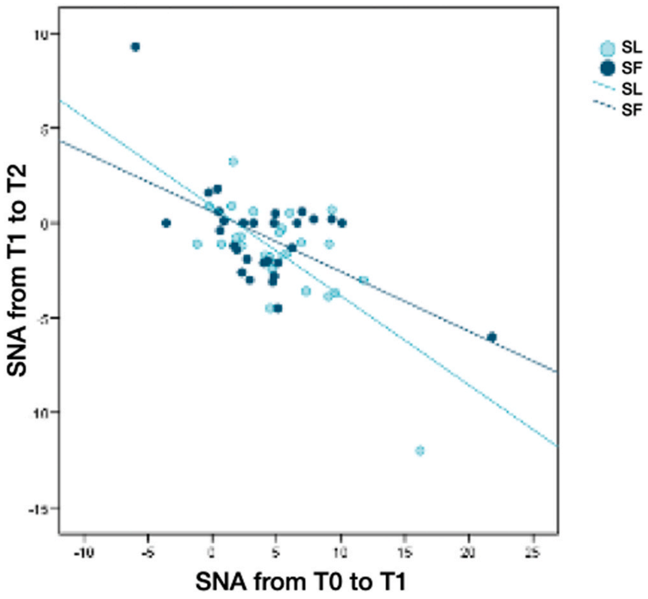

Fig. 3. Graph showing a moderate to strong correlation between SNA angle opening during surgery and SNA angle relapse during follow-up for both groups independently; surgery-first group (SF), $r = -0.59$; surgery-late group (SL), $r = -0.68$. T0, preoperatively; T1, 1 month after surgery; T2, 1 year after surgery.

stable and therefore are also indicated for the SF approach.[32] According to the standardized ‘upper incisor to soft tissue plane’ planning protocol of the study centre,[19,22] the majority of patients underwent bimaxillary advancement movements, which could have contributed to the stability obtained in both groups. Regarding the fixation method, both intermaxillary fixation and biodegradable poly-70 L/30 DL-lactide plates provide less stability than titanium plates.[33,34] Additionally, some authors recommend maintaining a surgical occlusal wafer postoperatively for occlusal guiding in the SF approach to improve occlusal stability,[35] although our protocol only contemplates using it in segmental Le Fort I cases, regardless of the surgical timing protocol.

On the other hand, some authors report that the magnitude of surgical movement following the SF protocol would be larger than the conventional approach because of the additional

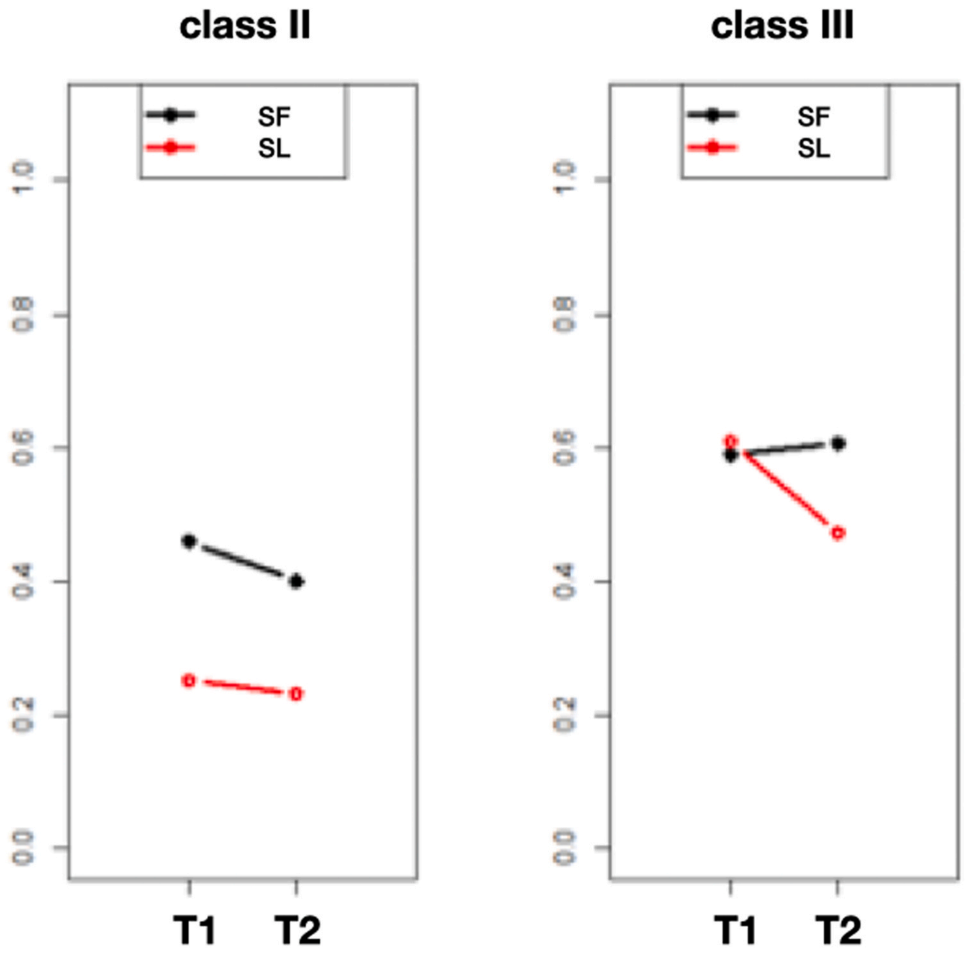

Fig. 4. Graphs showing the association between dental class and SNA angle relapse: a significantly greater relapse was observed only in Class III patients in the SL group ($P = 0.013$). SF, surgery-first; SL, surgery-late; T1, 1 month after surgery; T2, 1 year after surgery.

amount of surgical movement of the maxilla or the mandible needed to cover the decompensatory pre-surgical orthodontic movements used in the conventional approach.[36] In the same context, a meta-analysis conducted by Wei et al.[18] in 2018 found a greater relapse of B point both vertically and horizontally in the SF group in cases of skeletal Class III malocclusion, due to a more pronounced counterclockwise rotation of the mandible during surgery in these patients. They suggested the reason for the high relapse tendency of the mandible may be associated with temporomandibular joint dysfunction and/or muscular factors.[18,37]

However, according to the protocol followed at Teknon Medical Center, whenever the surgical plan differs from the one that would be designed in a conventional SL scenario, this should be a contraindication in itself for a SF approach[19]. Examples would be the need to perform segmental surgery to compensate for transverse dentoalveolar torque problems, adding a genioplasty to compensate for a poor torque of the lower incisors, or the need to perform mandibular remodelling to compensate for posterior vertical dentoalveolar asymmetries. These modifications to the surgical plan could increase the risk of relapse, and therefore are not suitable for a SF approach, and would require preoperative orthodontic treatment. In some cases, a reduced preoperative orthodontic preparation can be feasible, and a so-called surgery early (SE) orthognathic approach can be followed. This entails a minimum orthodontic preparation lasting less than 6 months, for slight tooth decompensations or torque corrections, generally without tooth alignment or levelling. In patients not suitable for a SF approach, with this short preparation, postoperative stability can be achieved with less risk of relapse. This is only possible if the surgical-orthodontic team work together with a unified planned treatment objective, both before and after surgery[1].

Due to the strict criteria of indications for a SF approach applied, the present study results demonstrate a wider magnitude of movements in SL cases, as evidenced by the significance for PNS-z, A point-z, and SNA angle measurements. In this context, the SNA angle suffered a stronger relapse in Class III patients in the SL group ($P = 0.013$) (Fig. 4), since most Class III patients had an underlying sagittal maxillary hypoplasia and therefore required a greater maxillary advancement. The higher relapse rate is in line with the published literature, which reports that skeletal relapse is directly correlated to the surgical amount of movement.[34,38]

Shortcomings of this study are its retrospective and single-centre design, with the inherent biases involved. Nevertheless, the results are consistent with those found in the literature, showing an equivalent 3D stability between SF and SL protocols at 1 year of follow-up.

Therefore, the surgery-first approach is a feasible option for an immediate improvement in skeletal discrepancy and facial aesthetics, and also of the upper airway volume for patients with sleep-related breathing disorders, with 1-year follow-up stability equivalent to that of the surgery-late protocol. The authors recommend a correct pretreatment planning by the surgical-orthodontic team and strict adherence to the inclusion and exclusion criteria for the surgery-first approach.

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None.

Competing interests

None.

Ethical approval

Approval obtained from Quiron Teknon Ethics Committee (Ref. SF-SC).

Patient consent

No.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijom.2022.06.016.

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